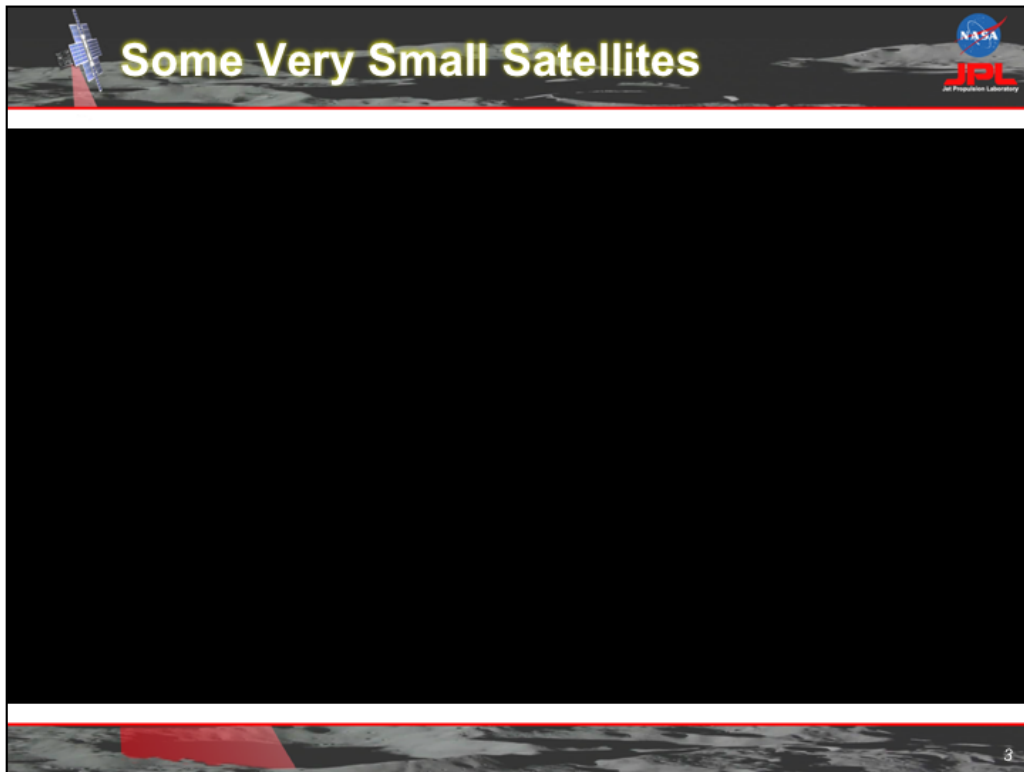


Image from the LF project



NASA video



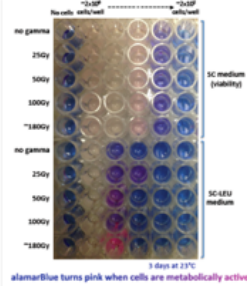
NASA Video

<https://www.youtube.com/watch?v=FhzyIWKvo9Q>

To Very Far Places



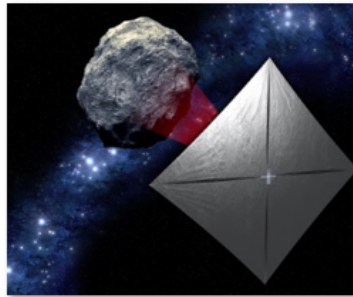
Biosentinel:
DNA damage-
and-repair
experiment
using
microfluidics



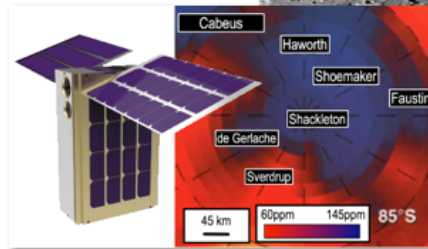
Lunar IceCube: Characterize
surficial water and its variability
using a passive IR
spectrometer (1-4 μm)




LunaH-map: Deep polar H
deposits at the lunar south
pole with low-altitude
neutron spectroscopy




NEA Scout:
Characterize
a near-earth
asteroid's
volume,
spectral type,
spin and
orbital
properties





Lunar IceCube

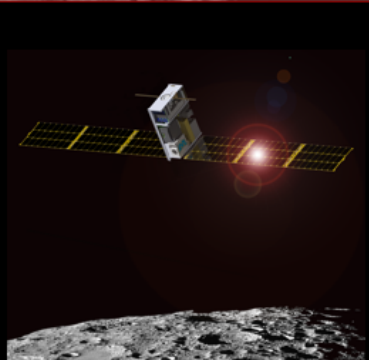


Mission Description and Objectives
 Lunar IceCube is a 6U small satellite whose mission is to prospect for water in ice, liquid, and vapor forms and other lunar volatiles from a low-perigee, inclined lunar orbit using a compact IR spectrometer. 1.) Lunar IceCube will be deployed by the SLS on EM-1 and 2.) use an innovative RF Ion engine combined with a low energy trajectory to achieve lunar capture and a science orbit of 100 km perilune.

Strategic Knowledge Gaps
1-D Polar Resources 7: Temporal Variability and Movement Dynamics of Surface-Correlated OH and H₂O deposits toward PSR retention
1-D Polar Resources 6: Composition, Form and Distribution of Polar Volatiles
1-C Regolith 2: Quality/quantity/distribution/form of H species and other volatiles in mare and highlands regolith (depending on the final inclination of the Lunar IceCube orbit)

Technology Demonstrations

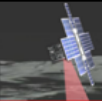
- Busek BIT 3 - High isp RF Ion Engine
- NASA GSFC - BIRCHES Miniaturized IR Spectrometer - characterize water and other volatiles with high spectral resolution (5 nm) and wavelength range (1 to 4 μm)
- Space Micro C&DH- Inexpensive Radiation-tolerant Subsystem
- JPL Iris v. 2.1 Ranging Transceiver
- BCT- XACT ADCS w/ Star Tracker and Reaction Wheels
- Custom Pumpkin- High Power (120W) CubeSat Solar Array




Current Status
 Team is preparing for CDR. All critical / long-lead Flight hardware has been ordered.
 FlatSat with non rad-hard subsystems and emulators is in development
 Trajectory, navigation, and thermal models along with communications links, mass, volume and power budgets evolving


PDR	Phase 1	CDR	Phase 2	Phase 3	FRR/ORR	Launch	Mission Ops	Mission Duration	Project Closure
05/19/2016	06/20/2016	06/28/2017	07/20/2017	03/02/2018	03/21/2018	10/15/2018	10/15/2018	2 years incl. ext.	04/30/2020

Slide provided by Lunar IceCube PI B. Malphrus



LunaH-map (Lunar Hydrogen Mapper)

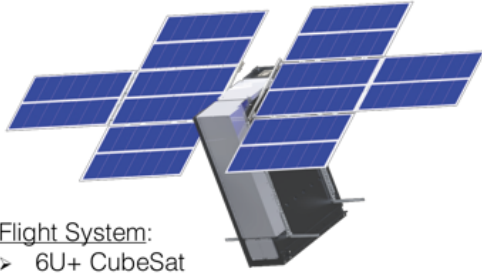




Miniature Neutron Spectrometer (Mini-NS):

- CLYC-based epithermal neutron detector
- Epithermal neutron suppression indicates enhanced hydrogen
- Synergistic with previous missions including Lunar Prospector and Lunar Reconnaissance Orbiter

LunaH-Map will use a neutron spectrometer to constrain hydrogen abundances at the lunar South Pole at small (<10 km²) spatial scales.



Flight System:

- 6U+ CubeSat
- SMD SIMPLEx program
- Launch on SLS EM-1 in 2019
- Two month science phase in 15x3150 km polar orbit
- Busek BIT-3 ion thruster
- Blue Canyon Technologies XB1 CDH/EPS/ADCS
- MMA eHawk+ gimbaled solar arrays
- NASA JPL Iris V2 deep space transponder

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Images provided by C Hardgrove, LunaH-map Principal Investigator.



MarCO



MarCO (Mars Cube One): 2 6U satellites flying with Insight mission (2018) carrying radios to provide UHF (receive only) and X-band (receive and transmit) functions to relaying EDL information received from Mars Reconnaissance Orbiter



Images from NASA at
<https://www.jpl.nasa.gov/cubesat/missions/marco.php>

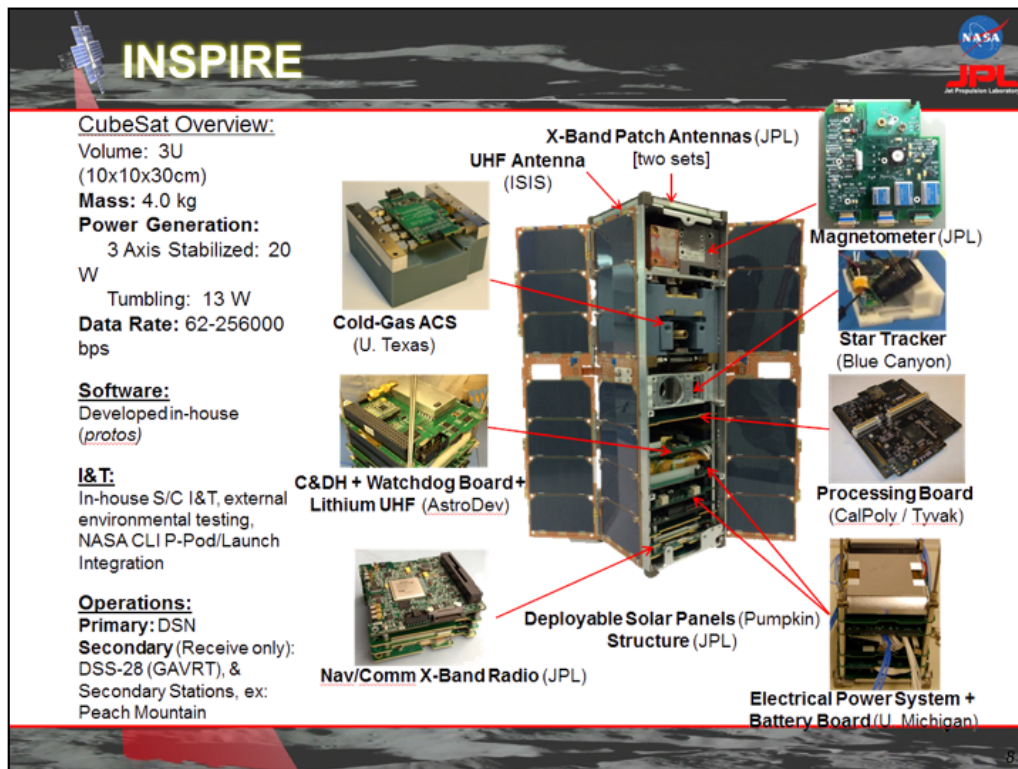
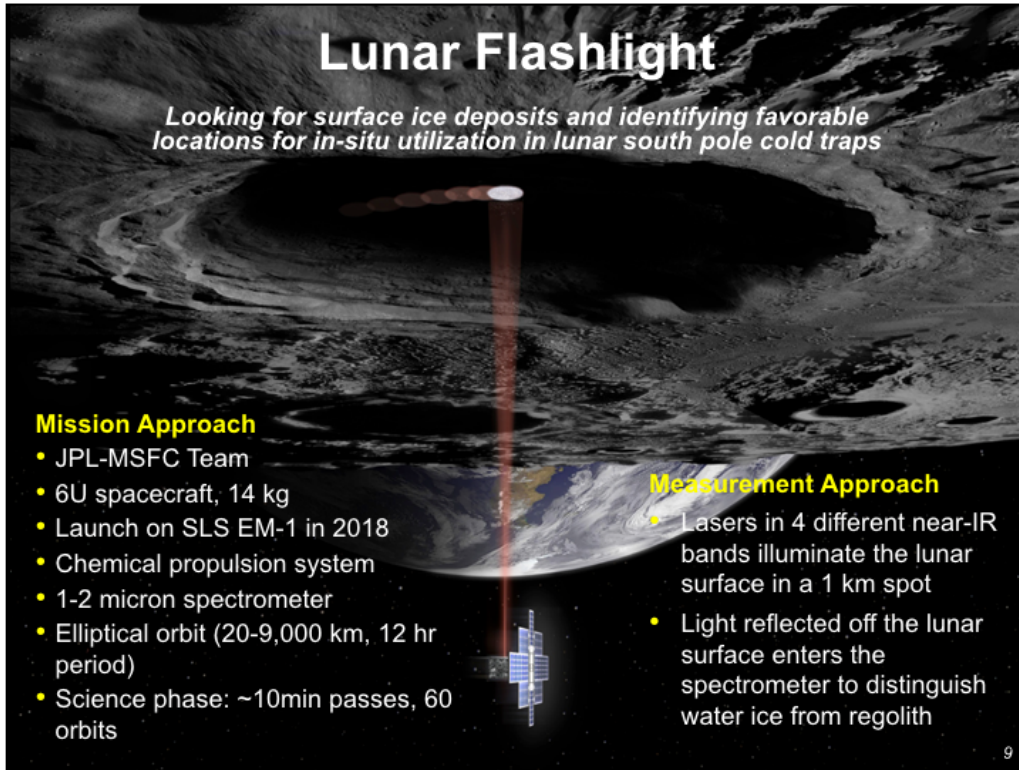


Image from NASA at
<https://www.jpl.nasa.gov/cubesat/missions/inspire.php>

Lunar Flashlight

Looking for surface ice deposits and identifying favorable locations for in-situ utilization in lunar south pole cold traps



Mission Approach

- JPL-MSFC Team
- 6U spacecraft, 14 kg
- Launch on SLS EM-1 in 2018
- Chemical propulsion system
- 1-2 micron spectrometer
- Elliptical orbit (20-9,000 km, 12 hr period)
- Science phase: ~10min passes, 60 orbits

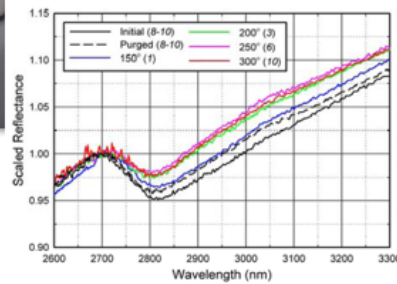
Measurement Approach

- Lasers in 4 different near-IR bands illuminate the lunar surface in a 1 km spot
- Light reflected off the lunar surface enters the spectrometer to distinguish water ice from regolith

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Image from the LF project

Water on the Moon



- Moon rocks are drier than any known terrestrial rock – no hydrous minerals like mica, amphibole, clay minerals, hydrous iron oxides
- All returned lunar samples have adsorbed water on their surfaces – thought to be terrestrial contamination (and probably most of it actually is)

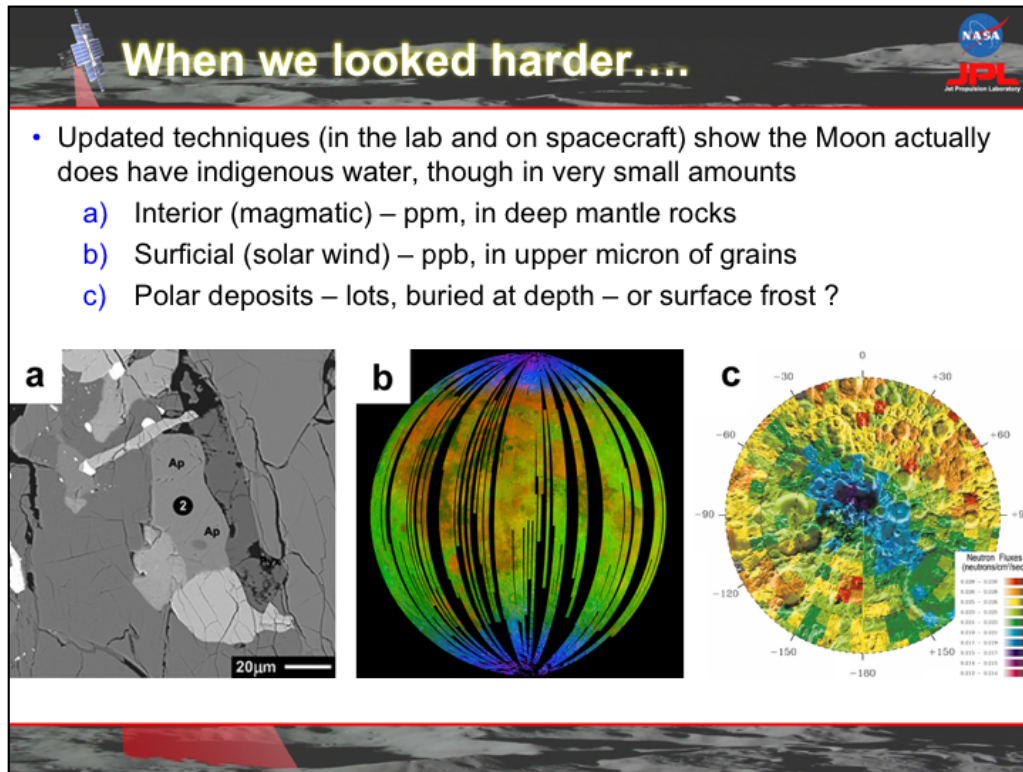
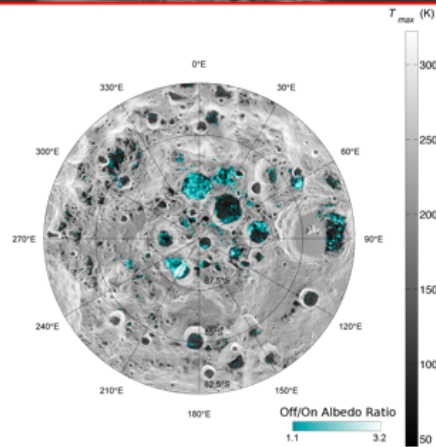
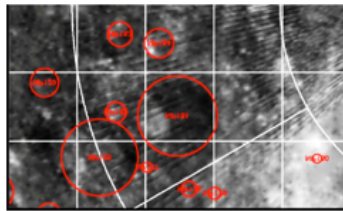
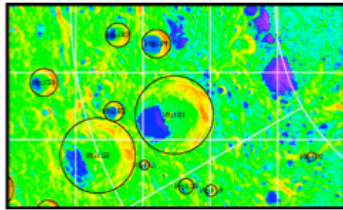


Image created by author

Water ice frost in PSRs?



- Cold temperatures (Diviner) correlate with high albedo at $1.064 \mu\text{m}$ (LOLA) (Zuber et al. 2012, Lucey et al. 2014, Haruyama et al. 2013)

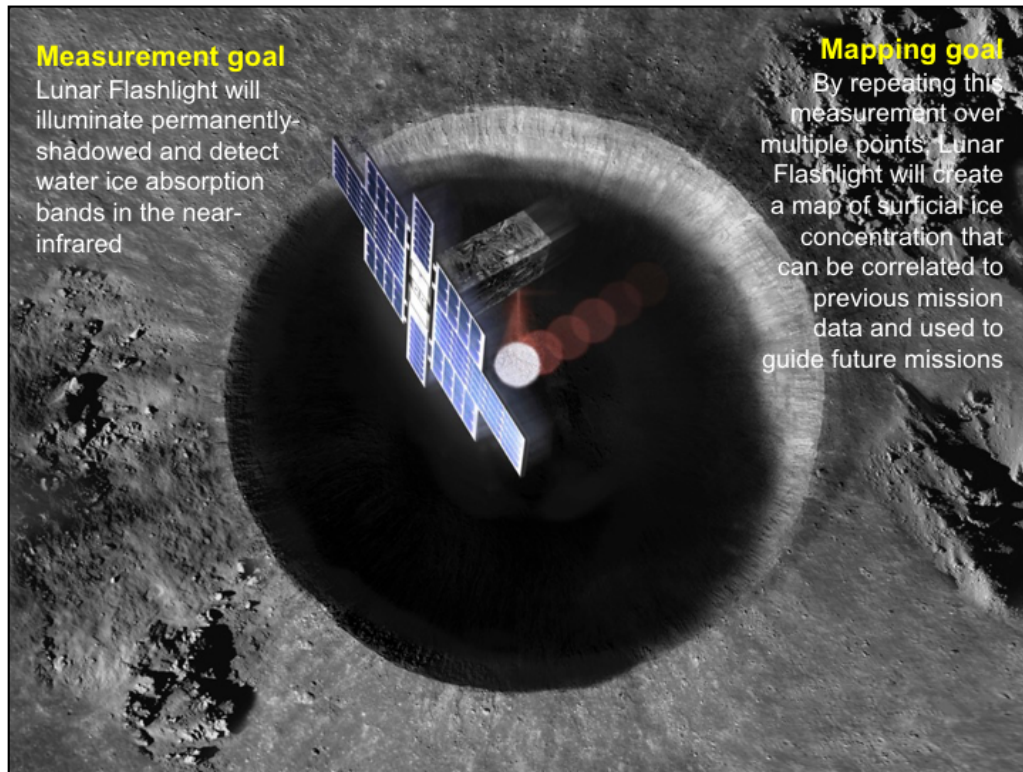
- Also correlated with high ultraviolet albedo data from LAMP (Hayne et al. 2014)

Water is a resource



- Humans exploring the Moon will need water:
 - Option 1: Carry it there. ↵ expensive (at \$10K/lb, 1 gal H₂O=\$80K)
 - Option 2: Use water that may be there already. ↵ “live off the land”
- Can mine O₂ from minerals and H from solar wind implantation, however, this is very energy intensive
- Life would be much easier and cheaper if we could use H₂O from the Moon
- **At the surface or near surface**
- **In “operationally useful” quantities**





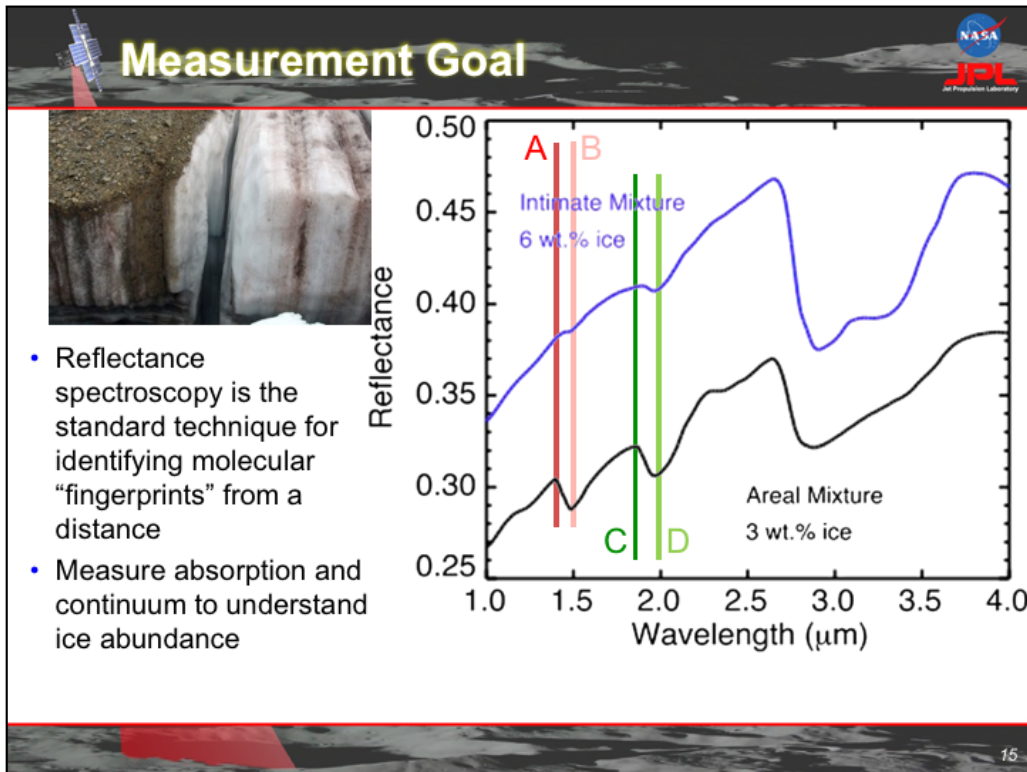
Measurement goal

Lunar Flashlight will illuminate permanently shadowed and detect water ice absorption bands in the near-infrared


Mapping goal

By repeating this measurement over multiple points, Lunar Flashlight will create a map of surficial ice concentration that can be correlated to previous mission data and used to guide future missions



Image from the LF project



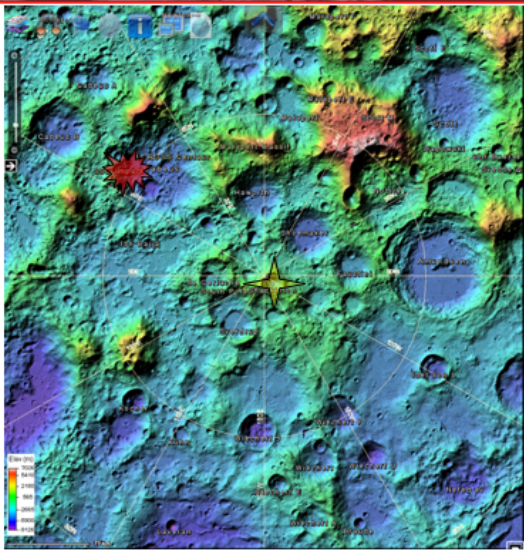
Images created by the author



Mapping Goal

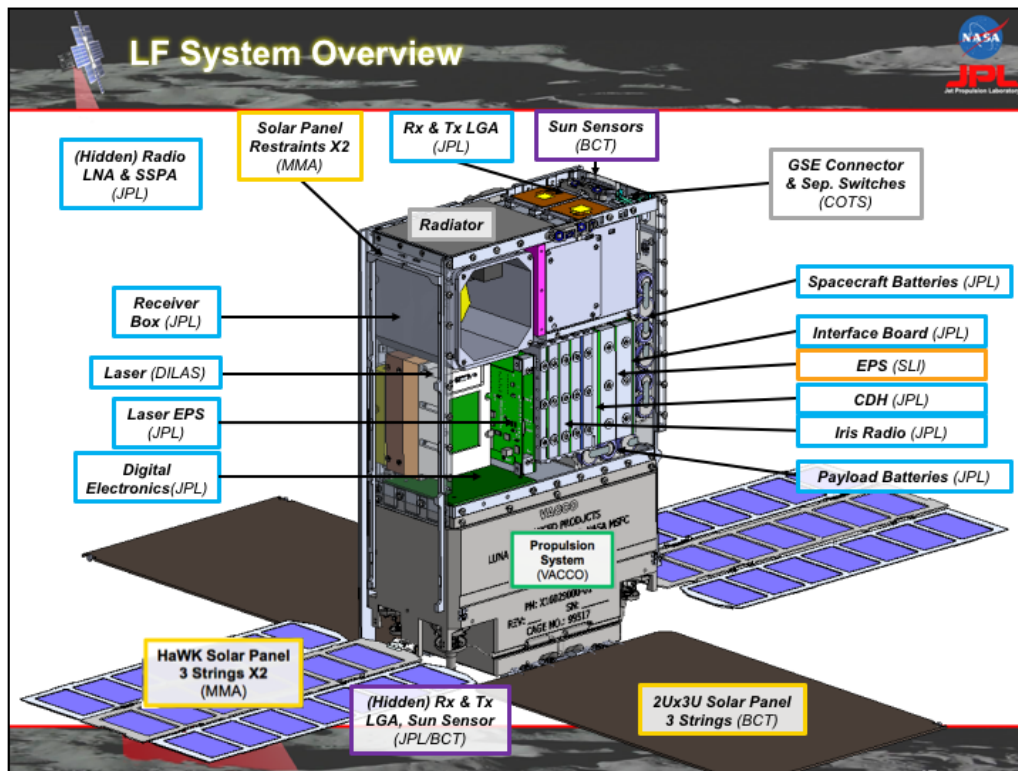
- Measure water ice at multiple locations within PSRs at one pole at ~1-2 km footprint per spot
- This is an *operationally useful* scale for future landers and rovers
- Enables prediction of other ice deposits by correlating data with other mapped geologic characteristics, including latitude, temperature, topography, lighting, proximity to young fresh craters, etc.



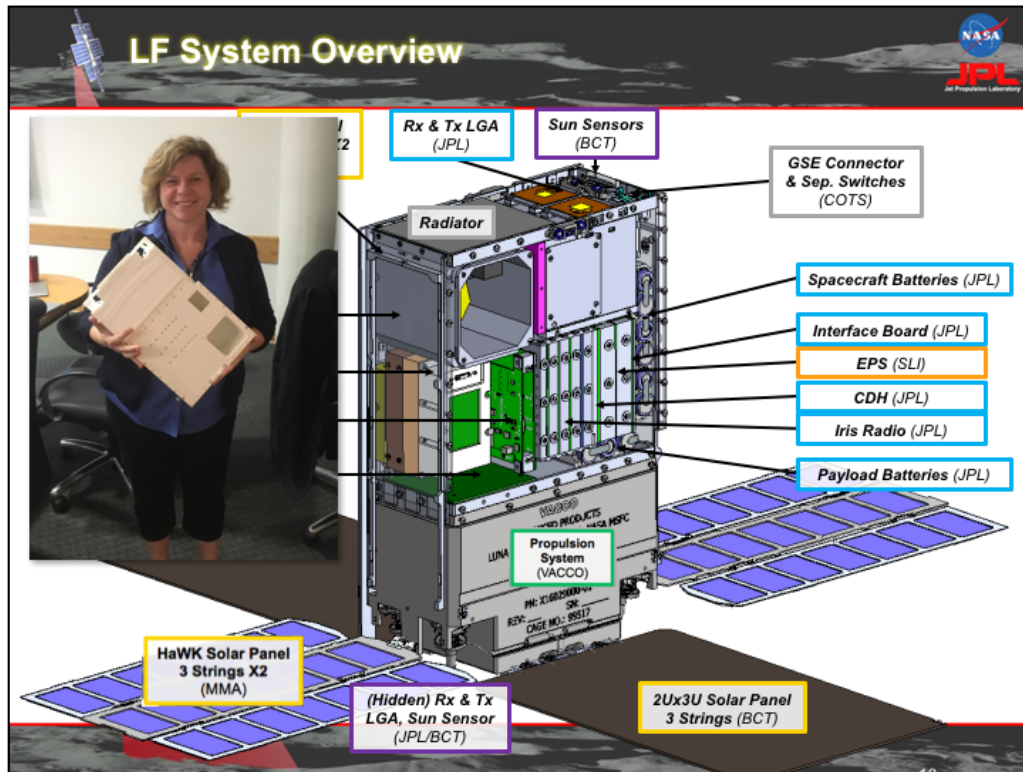
LOLA topographic map for the South Polar region from 80S showing large craters and PSRs

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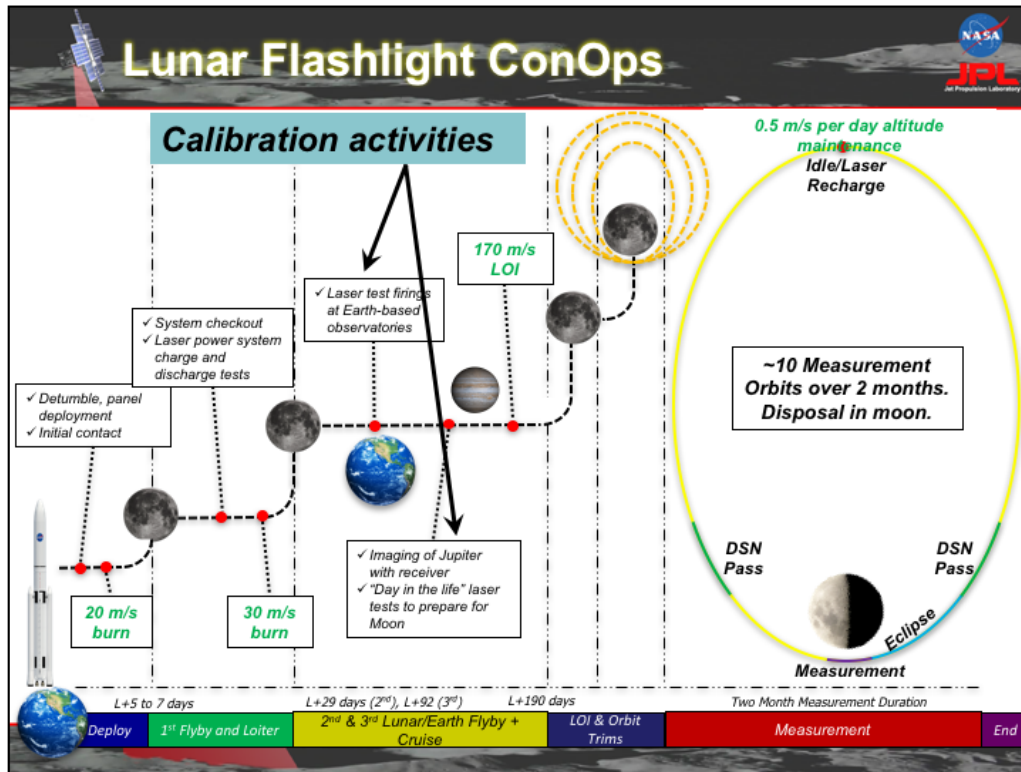
NASA image



LF project image



LF project image



LF project image



From LEO to beyond



Environment / mission design

- Thermal management: Space has extreme thermal environments. The lunar thermal environment is one of the most challenging in the solar system, due to high infrared and solar emission on dayside (~400 K), and very cold (90-100 K) on night side
- Radiation Hardening/Tolerance: few COTS options exist for subsystems that are rad-hard or rad-tolerant.
- There is a lack of detailed information/schematics/parts lists for COTS subsystems to assess performance in thermal and radiation environments
- Longevity. There are some mission concepts that require one, two or even many years of operation. That's not such a big deal for regular spacecraft, but for COTS cubesat parts and subsystems, that can be a real issue.



From LEO to beyond



Propulsion and trajectory

- Significant research into small, solid-state thrusters is needed for ACS and probably also for delta-v.
- Small reaction wheels will saturate very quickly when trying to do any kind of pointing-dependent science, and without a mag field to push against (e.g., with magnetic torque coils) we're dependent on thrusters or solar wind magic.
- Possible science targets are strongly dependent on the launch vehicle's trajectory characteristics.
- Significant requirements for safety assurance levied by launch services provider for escape-velocity LV



From LEO to beyond



Communication

- Can't use UHF in deep space – have to use X-band radios and there's only one right now.
- Therefore also need to acquiring adequate aperture time on the DSN for ranging and for data downlink and commanding. Getting an appropriate volume of data, telemetry and (especially) ADCS data to the ground in a timely manner.
- Scaling power and communications to much greater distances from Earth leads to pressures on volume and mass, thermal control
- Communications uplink/downlink opportunities are limited - don't get to talk to your cubesat as often if it's in LEO. Fault tolerance/protection is a big deal because of that.



From LEO to beyond



Flight Software Development

- Flight software for deep space is significantly more complicated than CubeSat missions to LEO
- the extent of FSW development that's required for interplanetary spacecraft will be exhaustive. And then, of course, propulsion is huge and much different than LEO. I think managing the propulsion, operating it, are big issues that have really only been addressed by the bigger NASA missions so far.
- Ground Data Systems – deep-space spacecraft navigation, attitude control and pointing, etc. are additional data types – need to develop appropriate ground data processing systems and identify and learning to use relevant tools

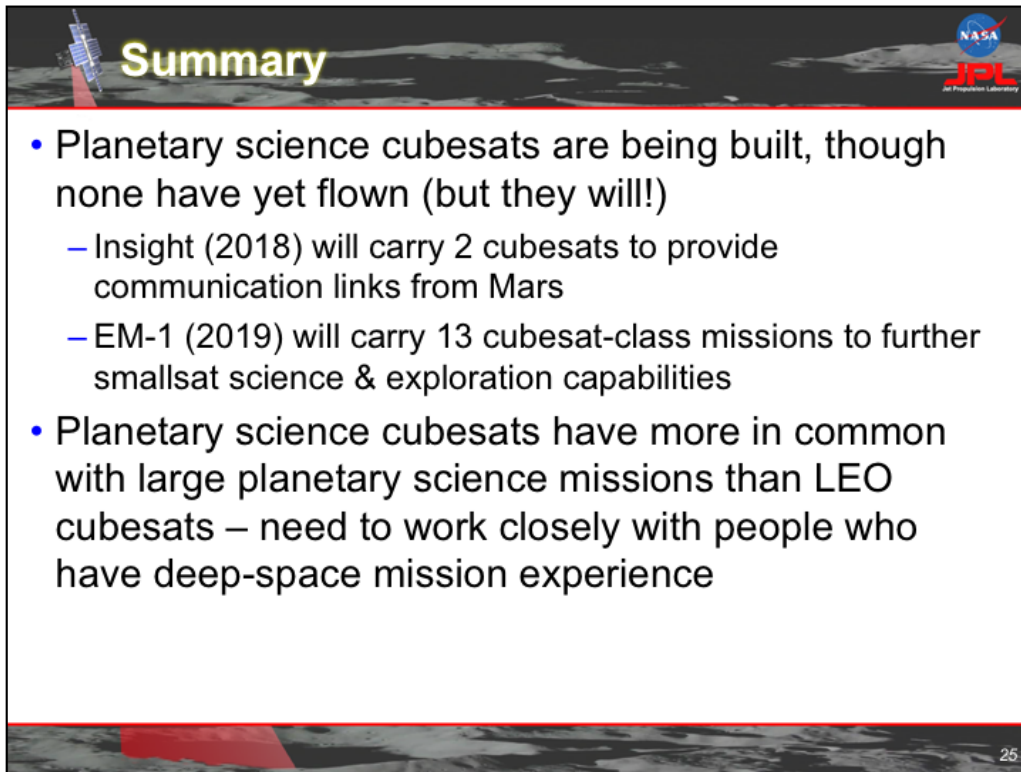


From LEO to beyond



Community expectations and norms

- Data archiving. NASA and the US planetary science community rely on the Planetary Data System (PDS) to correlate mission science results with correlative data such as instrument calibration, spacecraft pointing information etc. Ensure that results can be reproduced, tweaked, etc. long after mission team is disbanded.
- Managing Risk - working to accept and manage a level of risk that is non-conventional and appropriate to program resources
- Developing, integrating and testing spacecraft systems on a highly compressed timeline
- Developing unique designs. Every target and every science observation is different. This means less modularity and a lot of required mission design work – also requires detailed knowledge of the allowed mission design parameter space

The slide features a dark, textured background with a red horizontal line. In the top left corner, there is a small illustration of a satellite. In the top right corner, the NASA logo and the JPL (Jet Propulsion Laboratory) logo are displayed. The word "Summary" is written in a large, yellow, sans-serif font. Below the title, there are two main bullet points, each preceded by a blue dot. The first bullet point has two sub-points, each preceded by a blue dash. The second bullet point is a single line. The slide number "25" is located in the bottom right corner.

Summary

- Planetary science cubesats are being built, though none have yet flown (but they will!)
 - Insight (2018) will carry 2 cubesats to provide communication links from Mars
 - EM-1 (2019) will carry 13 cubesat-class missions to further smallsat science & exploration capabilities
- Planetary science cubesats have more in common with large planetary science missions than LEO cubesats – need to work closely with people who have deep-space mission experience

Author's photo